CFD ANALYSIS AND OPTIMIZATION OF PROCESS PARAMETRS OF ABRASIVEFLOW MACHINING

A thesis Submitted in partial fulfilment of the requirements for the award of the degree of

Master of Technology

In

Mechanical Engineering (Production Engineering)

By

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CERTIFICATE

This is to certify that the thesis entitled ― **CFD Analysis and optimization of process parameter of abrasive flow machining** submitted to the National Institute of Technology, Rourkela (Deemed University) by **MANGILALA THEJAVATH. Roll No. 213ME2410** for the award of the Degree of **Master of Technology** in Mechanical Engineering with specialization in―**Production Engineering** is a record of bonafide research work carried out by him under my supervision and guidance. The results existing in this thesis has not been, to the best of my knowledge, succumbed to any other University or Institute for the award of any degree or diploma. The thesis, in my opinion, has reached the standards fulfilling the requirement for the award of the degree of Master of technology in accordance with regulations of the Institute.

Place: Rourkela

Date

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Dedicated to my

Parents

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ABSTRACT

This study deals with an approach to understand the micro finishing of abrasive flow machining process, in which computational fluid dynamics is used to simulate the forces. The present work develops a CFD simulation of AFM of a cylindrical work-piece and a work-piece with irregular feature. Velocity profile and pressure distribution has been determined for a given extrusion pressure. Axial stress, radial stress and depth of indentation have been determined. Taguchi's technique is used to minimize the depth of indentation. A flexible polishing tool comprising of a polishing medium is used to carry out the analysis. It is found that mesh size has significant effect on outputs followed by velocity and pressure. The simulation is also partially validated with experiments.

Keywords: AFM, CFD Simulation, Taguchi Design, ANOVA.

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CHAPTER 1

INTRODUCTION OF AFM.

Exactness (Precision) and Ultra finishing methodology represents a basic and costly period of the general production process. Manufacturing of high precision parts involves a final phase of finishing operation. For the most part, it is uncontrollable, labor consuming and usually bites a huge chunk of the total machining expenditure. The significant properties, like wear resistance and loss of machining energy because of friction, are effected by the surface roughness of the coordinating parts [1, 3].

To counterbalance the issues of high direct cost of manpower and to create polished precision components with particular highlights for finishing distant zones, abrasive finishing process is created. Abrasive finishing methodology is conveyed with a substantial number of cutting edges, which have inconclusive introducing. The abrasive fine process is generally utilized because of their ability of finishing different geometries of structure (i.e. Level, round and so forth.) with sought dimensional exactness and surface completion [1, 6].

1.1 Overview of traditional finishing process.

. The examples of conventional abrasive finishing processes are honing, micro honing and grinding. In lapping practice, geometry with high dimensional accuracy is attained for different shapes of surfaces. Usual surface shapes on which lapping is done are horizontal plate and cylinder-shaped work piece. Slurry made up of loose abrasive particles are used between the lap and the job to get the desired finish. Moreover it is observed that if the lap is moved slowly and the abrading pressure is kept low, fine finish is obtained.

Honing is often thought as a smoothing technique than material removal operation. This methodology typically carried out at low cutting velocity, low load and substantial contact area.

A rigid tool comprising of abrasives is used in this technique. Typical motion imparted to this tool is low reciprocating movement and angular velocity inside the workpiece. This results in surface irregularities.

Super-finishing is a low speed rubbing technique requiring a fine rough stick fixed to a holder. This stick is mildly pressed against the workpiece with a very small amount of pressure. Following this horizontal to and fro motion is given to the workpiece and oscillating/feed is given to the pressed stick.

Cutting, ploughing and sliding/grinding are the three material removal processes to which all the above finishing operations can be categorized. As the name suggest, cutting is obliteration of material, ploughing is rearrangement of the material and sliding is material alteration technique. The degree of material disfigurement and the change in surface irregularities relies strongly on the intensity of force induced and the quantity of active grating cutting edges present in abrasive finishing operation[1-3].

1.2 Advanced abrasive finishing process.

The current traditional methods are not capable of producing desired Nano/micro level finishing. Also, such finishing needs exclusive tools, more time expenditure which are not viable economically. Subsequently to take care of the present demand of commercial ventures, new finishing techniques with better performances are created. Abrasive jet machining is one of such successfully developed technique with an extensive range of application. Other techniques available are MAF, MRF and MFP, where the control of execution is done by the utilization of magnetic field [4, 5].

1.2.1 Magneto-rheological flow polishing.

The below fig. 1 shows Magneto-rheological flow polishing (MFP) and its procedure which depend on the Ferro-hydrodynamic conduct of a magnetic fluid that causes the ball to float.

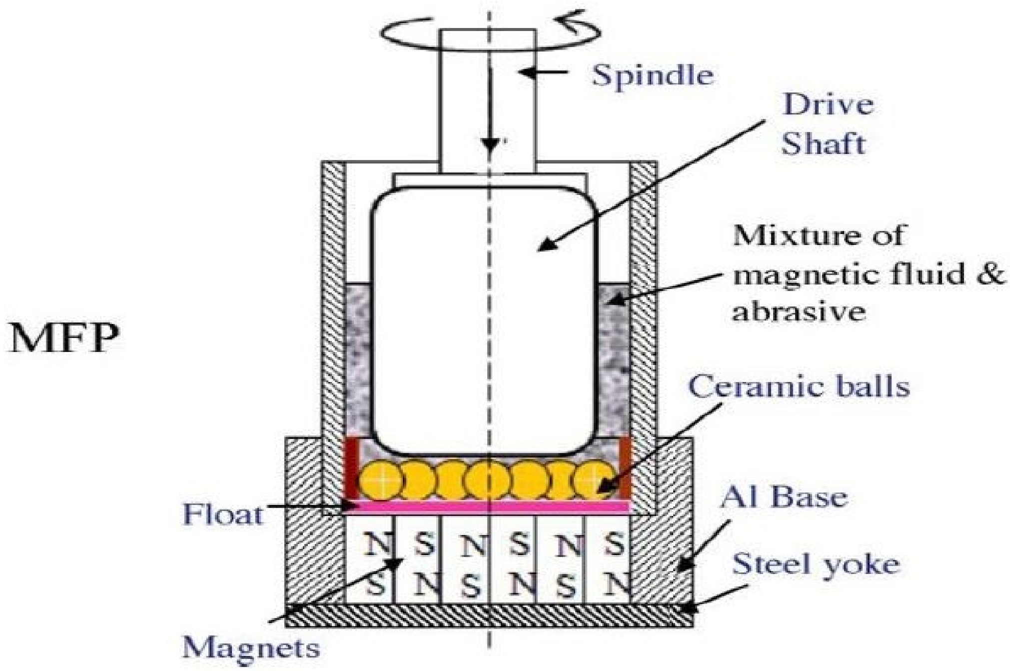

Fig . 1 Magneto rheological flow polishing[6].

The container holding a mixer of magnetic fluid and abrasive particles is used for machining. Limitation exerted on the geometry is that the shape of the component has to be spherical and flat. Drive shaft rotated by the spindle generates force which force the ball to levitate. That force is proportional to the magnetic field. It is extensively used for highly brittle material because of it being cost effective and reliable for finishing materials with high precision [1].

Magnetic- rheological flow polishing requires less polishing time compare to others. This process can be automated if the situation demands.

1.2.2 Magnetic Abrasive finishes (MAF)

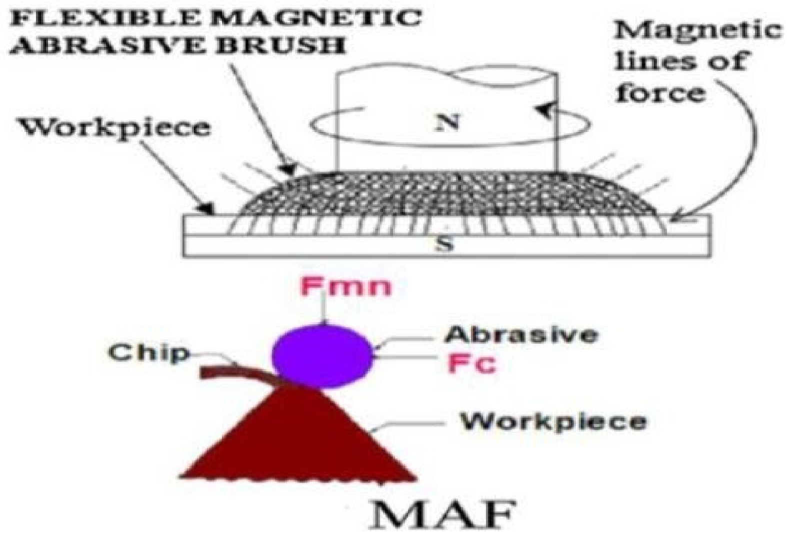

Fig . 2 Magnetic abrasive flow machining [6].

Fig.2 demonstrates Magnetic abrasive flow machining operation in which the work piece to be processed is arranged between two magnetic poles and the space between the work piece and magnetic poles are loaded with abrasive powder. This abrasive powder is utilized for surface and edge cutting. A mirror finish is obtained and the burrs are evacuated without changing the shape as the machining force utilized is significantly low [1-6].

MAF is commonly used in the finishing process of metals and ceramics. A respectable quality inside and external finish in both cylindrical and flat surfaces is created in this process.

1.3 LIMITATION OF MAGNETIC FIELD ASSISTED FINISHING PROCESS.

- Variation in magnetic field amidst the AFM operation happens. It occurs because of the chips produced and non-uniformly disseminated abrasive molecule.
- Because of their extraordinary thickness, abrasive grain gets sedimented.

- For thick work pieces, these techniques can't be used due to the high depth of work piece. The magnetic field becomes very low in finishing region at high depth contrasted to the top surface where it is connected.

1.4 ABRASIVE FLOW MACHINING PROCESS (AFM).

Abrasive flow machining is one of the innovative finishing process and its machining was developed by Extrude Hone Organization, USA in 1960.

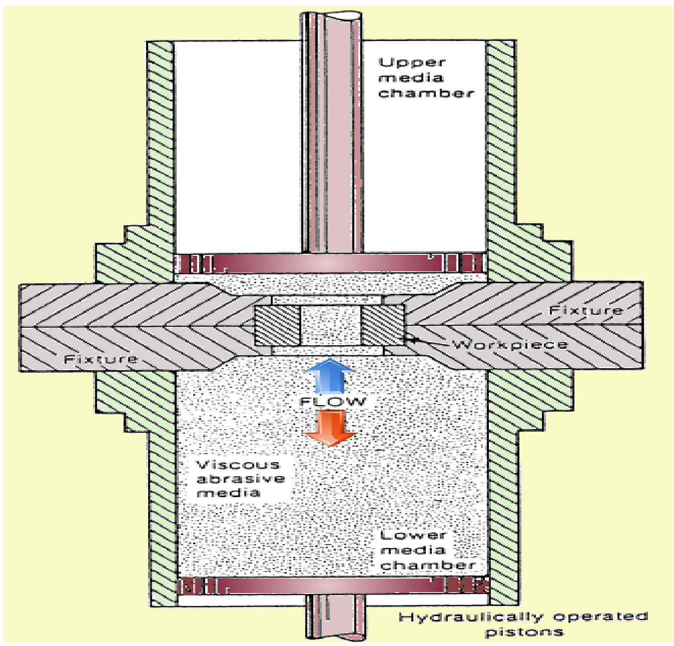

Fig. 3 Abrasive Flow machining[20]

AFM can be viewed as an approach of constructing a self –formingly device that can effectively uproots the workpiece material and finish those zones which are confined to the medium flow. AFM strategy is utilized for deburring, edge forming, and surface modifications. It is fit for finishing areas which are hard to reach by streaming abrasives, by blending with polymer of extraordinary rheological properties. AFM produces uniform, repeatable, and unsurprising results for finishing process.

Typically, the properties of transporter in AFM procedure assume a critical part. They ought to be visco-elastic and non-sticky in nature. Aluminum Oxide, Silicon Carbide, Boron Carbide and Diamond are normally utilized grating grains in the AFM process [1-6].

1.4.1 WORKING PRINCIPLE OF ABRASIVE FLOW MACHINING (AFM).

In this process, a visco-elastic matrix based polymer material is mixed with abrasive particle and additives, which called as the medium. Figure 4 consists of hose pipes, two vertical opposite cylinders, Hydraulic power pack, control box upper hydraulic cylinder and lower hydraulic cylinder.

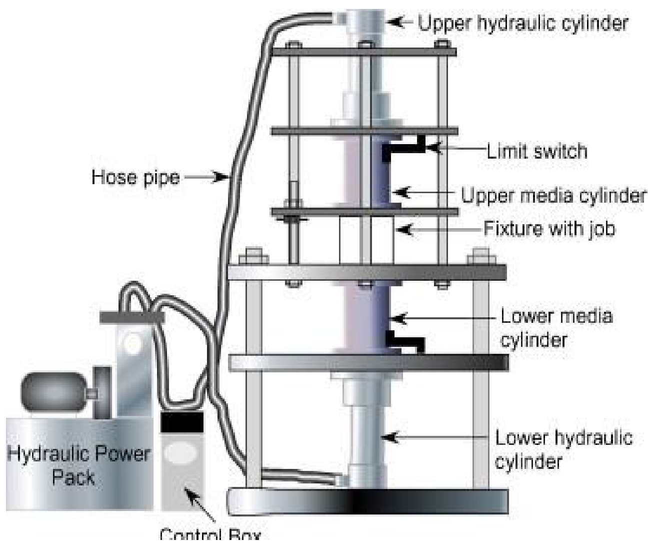

Fig. 4 Schematic diagram of the AFM [7].

The medium flows in two vertical opposite cylinders, i.e. upper medium cylinder and lower medium cylinder and through hydraulic power pack. The upper hydraulic cylinder and lower hydraulic cylinder are reciprocating in such manner that the respective pistons extrude the medium through the work piece and cause removal of workpiece material. When the medium comes out of the work piece material removal is done because of the extrusion pressure. Although ejected through the entrance shaped by the workpiece and tooling, this medium tries to complete the work piece surface precisely. Tooling undertakes an essential part of this approach. So tooling or fixture configuration has to be done precisely [1-7].

In view of the course through the limited entry of work piece area, the polymer chain holds the abrasive particles and moves them around toward extrusion pressures. Subsequently, the medium goes in as a multi-point cutting device and begins scraping the work piece surface.

Extrusion pressure, Number of cycles, work-piece opening surface roughness, and medium consistency are the noteworthy variable parameter having an effect on last surface roughness. The visco-elastic (non -Newtonian liquid blend with rough particles) medium travels along the administered pressure direction with axial velocity and axial force when adequate extrusion pressure is used. With the use of extrusion pressure and because of flexible element of the medium, radial force is generated, which results in entry of abrasives into the work-piece. Axial force supports removal of material as microchips by shearing the indented grating molecule in the axial direction. This system is relevant for many types of abrasive machining.

1.4.2 ABRASIVE FLOW MACHINING SYSTEM [1-4]:

Abrasive flow machining (AFM) system had three different elements i.e tooling, medium and machine.

Tooling.

The reason for Tooling or installation is to find and hold the workpiece in position, in addition to the work of directing the flow of medium. The tooling is made in such a manner that, it margins the distribution of medium in an area where the material evacuation is required.

Medium.

It is a mixture of polymer, rheological additives, and abrasive particles. Polyborosilaxane polymer is for the most part utilized as a part of this procedure. Another sort of polymer likewise can be utilized by work piece. Silicon carbide, boron carbide, alumina or diamonds is the regularly abrasive molecule utilized. The polymer goes about as a binder and to transmit extrusion pressure in distinctive course. The capacity of abrasive particles is to scrape the work piece surface when the medium streams over the confined section. The rheological properties of the medium are decided by its effective functioning [28,30].

Machine

Depends on the requirements, AFM machine can be designed in different sizes and plans. It comprises of framework, medium cylinder, hydraulic cylinder and control structure work. Usually the working pressure ranges from 1Mpa to 16Mpa.

AFM can be separated from different process in the fact that, it is possible to control and choose the concentration and area of spot abrasion through installation summary, medium select and methodology parameter.

1.4.3 Application of AFM [1-4]:

- Improve the mechanical fatigue strength of discs, edge finishing of holes and blades, hubs and shafts with controlled polish and cylinder piston.
- Improving airfoil surface settings on turbine sections and compressors
- Finishing attachment parts such as fuel stem nozzles, fuel control bodies and bearing components.
- Adjusting air flow opposition of blades, vanes, inner walls of combustion and diffusers.
- Abrasive Flow machining (AFM) is an advanced and very precise method of deburring, smoothing surfaces and producing controlled radii.

Fig .5 AFM is produced deburring and smoothing surfaces of complex parts[12].

- Extrude Hone is a process of abrasive Flow machining.this operation is recognized Worldwide for its ability to increase horsepower.

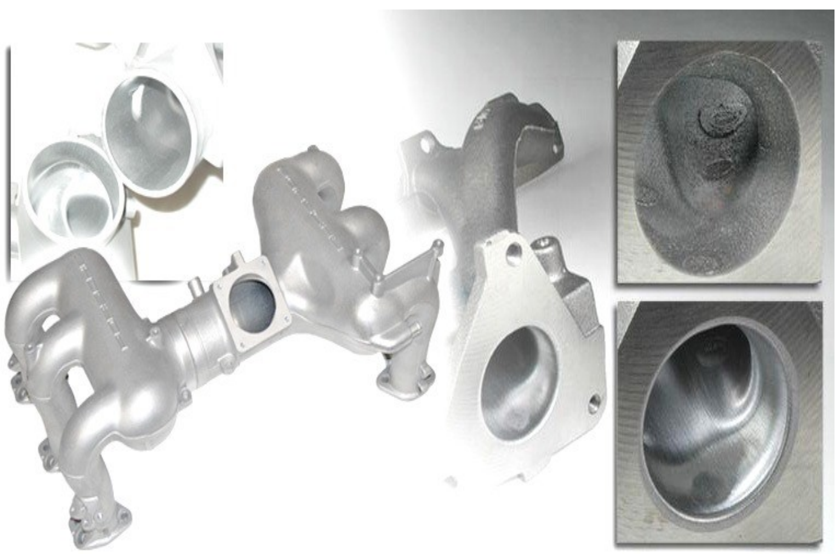

Fig .6 AFM of some complex holes[14].

- The removal of the brittle recast layer using Abrasive flow machining process to improve the quality.

Fig .7 AFM of cylindrical holes[25].

It is a well- known truth in automobile engineering, that it is exceptionally hard to achieve the surface finish in the inner path of admission ports because of complex shape. The surface enhancement is done by applying AFM methodologies to admission and air circulation system.

1.4.4 Features of AFM [3-6]:

- To deburr and refinement any inaccessible and multipath areas by forcing the abrasive medium into it.
- It also can polish in air, liquid, or fuel flows.
- It is possible to achieve extraordinary levels of surface finish and exactness.
- In AFM erosion of the workpiece can takings place where the flow is limited.

CHAPTER 2

LITERATURE REVIEW.

Abrasive flow machining (AFM) is a micro/nano finishing process on which a great quantity of investigative work has been done in the form of research papers, book chapters and patents. A brief analysis of same has been presented in this chapter. This review has been divided into other sub-sections as follows.

2.1 Abrasive flow machining (AFM) process mechanism.

Rhodes found that [11-14] in AFM process depth of cut by abrasive particles relies on size, relative hardness, sharpness of rough particle and extrusion-pressure. He expressed that medium viscosity assumes a key part in completing the activity. The media stream design which influences completing qualities depends upon machine settings, media plan and tooling arrangement. In the limited sections the viscosity of medium expands immediately and gives about pure extrusion of the medium. For scraping dividers of large sections, high viscosity medium was suggested and low viscosity medium was discovered suitable for reducing edges and for finishing thin entries.

Later Jain et.al. [2-4] advised to focus on effect of abrasive and mesh size on medium thickness at typical temperatures. They made-up a capillary rheometer and load tests were conducted to study rheological properties of the abrasive stacked polymeric medium. They assumed that raise in medium thickness prompts decline in surface roughness. It is concluded by numerous analysts that consistency of polymeric medium is a vital parameter which influence AFM operation.

An experimental study by Przyklenk [15] proposed that, the material removal limit of high viscous medium was around 300 times greater than that of low viscous base medium. The vital elements that impact stock removal and medium speed are abrasive rate (velocity), abrasive size and thickness of the medium.

Williams and Rajurker [16-21] conducted further analyses to study the impact of extrusion pressure and medium viscosity on material removed from the work piece and surface completion.

2.2 Medium composition and its rheology.

The medium is the principle component in the AFM procedure and it has the capacity to precisely scrape the chosen territories along which it flows. The medium is incorporated with a base transporter, abrasive particle and additives [24]. The base transporter is a high sub-atomic burden material with prevailing flexible properties and small viscosity. Rheological additives, for sample, plasticizers and conditioners are mixed into it, to enhance gooey things of the base transporter. The plasticizer as well as conditioners are low sub-atomic weight materials and can undoubtedly diffuse into high sub-atomic weight base polymer transporter when mixed [26-29]. The consistency of the medium abatement due to the dissemination of low sub-atomic weight drives the polymer chains to divide. In these blends abrasive particles are held by the polymer lattice material. High thick medium is rich in base polymer substance with a little measure of plasticizer. Subsequently, high thickness medium has moderately high versatile segments and subsequently this medium yield high rate of material removal every cycle. And low consistency medium carries on like liquid that smoothly passes through little breadth gaps [25-27].

Fletcher et.al. [22] attempted to expressed the thickness of the polyborosiloxane medium without abrasive molecule and got it as pseudo plastic in nature. Material withdrawal rate and surface finish in the AFM are fundamentally influenced by the medium's consistency which significantly abate with a little increase in temperature, and the thickness increases with a grating molecule orientation and it diminishes with grating molecule size.

2.4 Force and Specific Energy.

To evaluate the forces on a solitary abrasive grain in AFM procedure, Jain and Jain [19] exhibited a force analysis taking into account scraped spot hypothesis. From the analysis they anticipated the specific energy in AFM and contrasted it. The extent of specific energy in AFM could be utilized to predict the mechanism the system includes in surface generation.

2.5 Active Grains.

William and Rajurkar [18-21] prescribed that the quantity can be acquired by utilizing the pseudo-recurrence connected with the essential root from the information subordinate framework model of the AFM producing surface profiles. The quantity of element dynamic grains over a unified range of expulsion section is accomplished by

Cd =frequency x time for one stroke/cross-sectional area

Jain [18] discovered the dynamic grain thickness by numbering the quantity of impinging grains over the medium surface. They depicted the dynamic grain thickness increments with the focus and grating cross section size.

2. 6 Surface finish and material removal mechanism.

Davis and Fletcher [22] depicted the relationship between the quantity of cycles, temperature, and pressure drop and the kind of polymer and the grating fixation utilized. An increment in temperature brings about abatement in viscosity and increment in medium stream rate. With increment in completing time the medium temperature expands that results in rise of medium viscosity. The adjustment in temperature is mostly because of the inner shearing of the medium and the abrasion process.

Rhodes [11-14] explored through experiments that, the essential standard of AFM procedure and distinguished its procedure control variables. He expressed that when the medium is abruptly forced through the limited entries its viscosity rises. Significant material evacuation is watched when the medium is thickened. The scraped area effectiveness amid AFM relies upon tooling and fixtures. Complex volume of the medium will take almost at more number of communication between abrasive particle and the work piece; hence more scraped area every number of cycle will materialise. When contrasted with turned and processed surface sported EDM surfaces are discovered to be more suitable for AFM process. Since the machining surfaces produces diverse surface compositions and forms.

2.7 Representation of surface roughness:

Jain [5] recommended that there is a need for deliberate system for the choice of an arrangement of parameters to speak about the surface roughness, which satisfies the accompanying essential conditions.

1. Describe the geometric feature of the surface.

2. Measurable by commonly available instruments

3. Applicable in research

4. Enable precise interpretation.

Jain [4, 5] determined that, in production inspection, extraordinary quality surface would be tested by testing the parameters such as CLA value and mean slope of profile. He concluded that for stable and well controllable production process the second parameters need not to be checked regularly.

2.8 Some advances process on AFM process.

2.8.1 Magnetic AFF process:

Singh and Shan [10] utilized the medium made of silicon polymer base carrier, hydrocarbon gel and attractive abrasive particle in Magnetic AFF set up. Attractive field is connected around the work piece and watched that attractive field influences the material evacuation rate and surface irregularities.

2.8.2 Centrifugal force assisted Abrasive flow machining process:

In this process a tiny rod is placed at the center of the medium slug in the work piece concluding region. Here the rod strikes the abrasive particle that come in interaction with it. The angle of impingement of abrasive particle depends on rotational speed and shape of the rod. This process increases the finishing rate by 70-80%.

2.8.3 Drill-bit guided Abrasive flow finishing process:

In a drill-bit guided AFF process, a spontaneously rotatable drill bit is positioned with the help of a different fixture plates in the work piece destroying zone. By the mixture of medium reciprocation, medium flow rate from side to side the drill bit flute and scooping flow crosswise the flute the actual path of movement of abrasive particle absolute. This kinds the abrasive particle to move in an inclined motion rather than to move in a straight-line motion. Turbulence at the center is also roots frequent reshuffling of abrasive particle. Thus material removal rate and finishing activities well as surface roughness is also better.

2.8.4 Electro- chemically assited Abrasive flow machining process:

Electro-synthetically helped abrasive flow machining procedure which utilizes polymeric electrolyte, for example, gelated polymers and water gel as base transporter. The conductivity of electrolyte utilized in customary substance machining procedure is commonly lower than the particle conductivity of electrolyte. The conductivity declines much more with the expansion of inorganic to electrolyte. The polymeric electrolyte medium constrained the through little bury anode crevice. This thusly brings about more noteworthy stream resistance of polymeric electrolyte which takes the type of semi-fluid glue. In level surfaces test examination have been done.

2.8.5 Spiral polishing:

In Spiral polishing a spiral-fluted screw is positioned at the Centre of the hole in Work piece to be done. Using additional energy source the screw is rotated. The rotational motion of the screw highs the medium since lower medium cylinder to upper medium cylinder and goes to finish the hole while fleeting done it.

2.8.6 Ultrasonic flow polishing:

Ultra-sonic flow polishing is grouping of AFM and Ultra-sonic machining. The medium pumped depressed the centre of the ultrasonically energized tool, flow radially virtual to the axis of the tool.

2.8.7 Limitation of Abrasive flow machining (AFM):

- for abrasive flow machining the rate of finishing is less
- In AFM process consists of two cylinders which have to be uni-axis.
- The rheological properties of medium degrade due to lengthy finishing time and thus finishing ability of the medium lessens in the latter half of the beneficial life.

2.8.8 Objective of the present work:

In the present work efforts are complete in finishing of homogenous copper material.

The main objective of the thesis is as follows.

- Simulation of the Abrasive flow machining with CFD analysis for cylindrical work piece and component with irregular features.
- Determination of MRR, Depth of indentation, radial force, and axial force.
- Determination of optimum process parameters for minimizing depth of indentation.

CHAPTER 3.

SIMULATION OF AFM.

In the abrasive flow machining process argued above, it is compulsory to create experiments for output results. Different input parameters are necessary for every output. Which is very time consuming and cost operational and not accurate due to the inevitable error in machine parts. So it is difficult to get the optimum input parameter for better results.

So the analysis of Abrasive flow machining using the software CFD (FLUENT) of ANSYS WORKBENCH-15 is done numerically. Then by getting the outputs and putting those into the equation, we got the required results.

3.1 ANSYS Workbench -15

ANSYS Workbench is a project-management task device. It can be considered as the top-level crossing point connecting all our product instruments. Workbench grips the data of information between ANSYS Geometry/ Mesh/ Solver/ Post-processing devices. This extraordinarily helps venture administration. You need not bother with stress over the individual documents on plate (geometry, network, and so forth). Graphically, you can see initially how a project has been manufactured.

3.1.1 Basic workflow.

Dragging an Analysis System onto the Project Schematic lays out a workflow, comprising all the steps needed for a typical analysis.

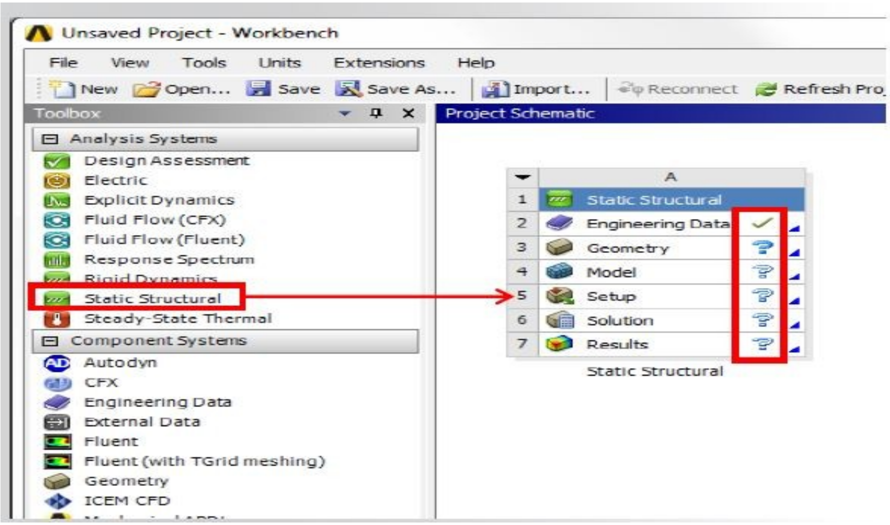

Fig.8 Basic flow of CFD.

Workflow is from top to bottom. As each stage is complete, the icon at the right-hand side changes.

3.1.2 Summary of the ANSYS Workbench.

Workbench is utilized to dispatch the individual software components, and used to interchange information between them. It is anything but difficult to see at-a-glace how a model has been built, and figure out which documents were operated for a definite simulation (pairing geometry records to solver runs). Workbench in addition makes it nonstop to perform parametric analyses (without the client expecting to physically dispatch every application in turn), and makes it simple to reproduce multi-physical science positions like liquid structure connection.

3.2 Computational fluid dynamics (CFD).

Computational Fluid Dynamics (CFD) which is the science of predicting fluid flow, mass transfer and heat, chemical reaction and phenomena. Main role of the CFD is to predict these phenomena; CFD solves equations for conservation of mass, momentum, energy etc…

3.2.1 CFD can provide detailed information on the fluid flow behavior.

- Distribution of pressure, velocity, temperature, etc.
- Forces like Lift, Drag.. (External flows, Aero, Auto…)
- Distribution of multiple phases (gas-liquid, gas-solid…)
- Species composition (reactions, combustion, pollutants…)
- Much more…

3.2.2 CFD is used in all stages of the engineering process.

- Conceptual studies of new designs
- Detailed product development
- Optimization
- Troubleshooting
- Redesign

3.2.3 Discretization methods in CFD.

The unfaltering quality of the picked discretization is for the most part known numerically as opposed to systematically as with straightforward direct issues. We must be wary to verify that the discretization is taking care of broken arrangements exquisitely. The Euler mathematical statements and Navier- stokes comparisons both accept stuns, and interaction surfaces. A portion of the discretization routines being utilized are codes, this ordinary system is utilized on discrete control volumes.

3.2.4 **Finite difference method**.

This procedure has old essentials and is cool to program. It is first just utilized as a part of minimal specific codes. Current limited distinction codes make utilization of an installed limit for treating complex geometries making these codes exceptionally powerful and precise. The frontier operated by the liquid is isolated into surface lattice in limit component technique. Where stuns or shorts are existing, high-determination plans are utilized. the utilization of second or higher request numerical game plans that don't presents produced motions is expected to catch sharp changes in the arrangement.

3.2.5 Finite element method.

For basic investigation of solids, this strategy is predominant, but on the other hand is fitting to liquids. In any case, extraordinary consideration to guarantee a traditional answer for the FEM plans. For utilization with the Navier-Stokes mathematical statements, the FEM configuration has been adjusted. It is much steadier than the FVM system, albeit in FEM preservation must be dealt with. Later CFD is moving in the new route. Typically, relentlessness/vigor of the arrangement is better in FEM however for a few cases it may take more memory than FVM systems.

3.2.6 Finite volume method.

.FVM redesigns the PDE's (Partial Differential Equations) of the N-S comparison in the customary structure and afterward discretize this mathematical statement. This sureties the safety of fluxes through a particular control volume. There is no confirmation that it is the distinct arrangement however the general clarification will be routine. Besides this technique is unpretentious to mutilated components which can dodge merging if such components are in basic stream locales. This joining technique delivers a technique that is indispensably routine (i.e. amounts, for example, thickness remain physically expressive).

3.2.7 Three key elements followed during CFD.

1. Pre- processing

2. Solver

3. Post processing

3.2.7.1 Pre-processing.

Under the pre-processing, we have to give geometry properties, fluid properties, and domain of geometry.

The arrangement of a stream issue (speed, pressure, temperature and so forth.) is characterized at pivots inside all cell which coincide with suitable limit conditions at cells that harmonize with the limit. Number of cells in the grid finish governs of the accuracy of CFD schedules. Generally, the greater quantities of cells improve the arrangement rightness. Both the thoroughness of the organization & its cost as far as key computer equipment & computation time are subject to the fineness of the lattice. Efforts are ongoing to enhance CFD codes with a (self) versatile cross section capacity. At last, such projects will naturally refine the framework in ranges of fast variety.

3.2.7.2 Solver.

- **Governing equation**

Employing continuity equation, the above model was solved in fluent component system

The mathematical representation of the medium in the AFM process includes basic equation of continuity and momentum equations.

$$\frac{\partial u_i}{\partial x_i} = 0$$

$$\rho\left[\frac{\partial u_i \partial u_i}{\partial x_i}\right] = \frac{\partial \rho}{\partial x_i} + \frac{\partial}{\partial x_j}\left[\mu\left(\gamma\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_i}{\partial x_i}\right)\right)\right]$$

Where ρ the density of fluid and u_i is the flow velocity in I- dirction.in the equation above the shear rate is derivable from the second invariant of the rate of deformation tensor ,D_{ij} and is given as.

$$\gamma = \sqrt{2D_{ij}D_{ij}}$$

Where,

$$D_{ij} = \frac{1}{2}\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_i}{\partial x_i}\right)$$

3.2.7.3 Post – processing .

The post – processing gvies out put results of geometry that include are .

- Domain geometry & Grid display
- Vector plots
- Line & shaded contour plots
- 2D & 3D surface plots
- Particle tracking
- View manipulation (translation, rotation, scaling etc.)

In the present study, a cylindrical work piece fixture completed up of brass taking internal slots in which the flat work piece is placed.

3.3 Geometry of work piece with fixture.

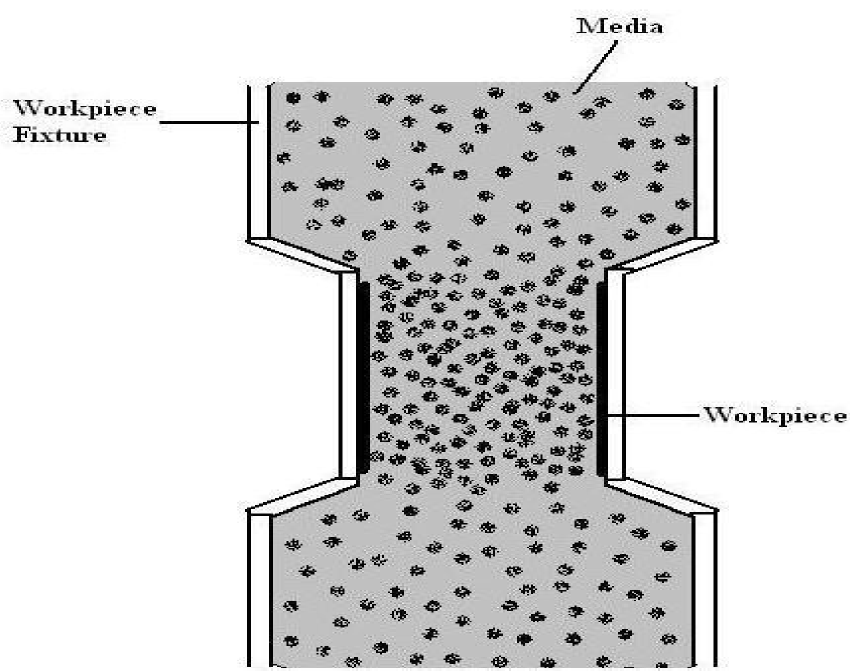

Fig.9 work piece with fixture [3].

3.3.1 Parameter setting of work piece.

- Properties of the cylindrical pipe work piece .

Material: copper

Brinnel hardness no: 35BHN

Ultimate tensile strength: 220Mpa

Yield strength: 70Mpa

Media: polyborosiloxane + grease,Density is 1219kg , Viscosity is 789kg/pa-s.

Abrasive: silicon carbide,Diameter =d_g=mesh grain size/(mesh number).

Mesh number=M_e =400 , d_g=22µm.

Work piece dimensions: Length is 100mm and Diameter is 5mm.

Fig.10 design of work piece.

The schematic diagram of the computational domain of the half of the work piece is shown in fig.

3.3.2 Boundary conditions.

- At inlet a uniform velocity profile and at exit a constant pressure is maintained with a fully developed flow condition.
- Along the wall, no slip boundary condition is applied.
- Along the axes of the cylindrical fixture, axis symmetric boundary condition is applied.
- The inlet pressure is 35 bar.
- The volume of fraction is 50 %.

3.3.3 Numerical method.

To simplify the analysis, following assumptions are made.

- The medium is homogenous
- The flow is quasistatic , incompressible and laminar
- The flow is axisymmetric.
- There is no swirling motion of the fluid.

3.3.4 Mesh geometry of cylindrical pipe.

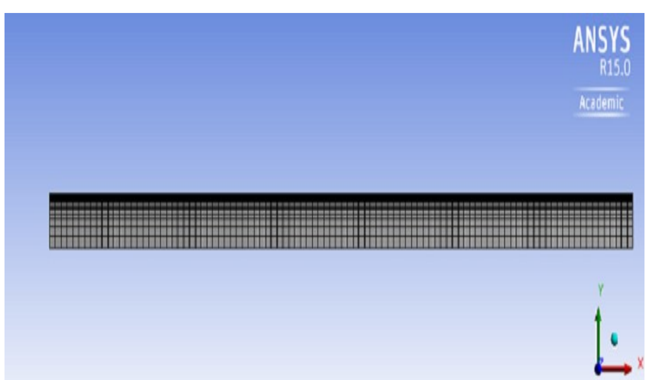

Fig.11 Quadrilateral Mesh geometry.

After giving name to all edges export the mesh file and select fluent file from drop down box and save it by giving proper name and close the mesh.

3.3.5 A fluent Analysis.

- Open the fluent start menu.

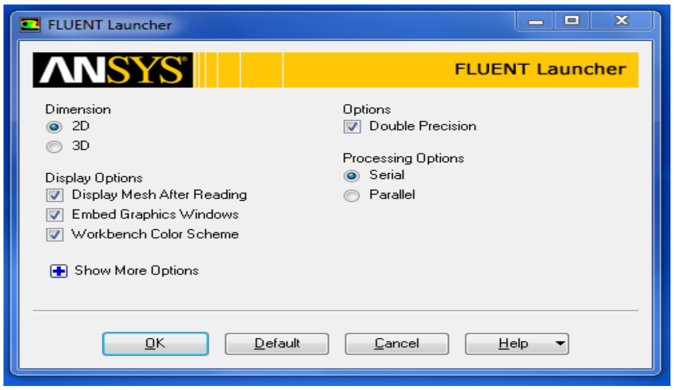

Fig.12 Fluent menu.

- Models- multiphase-edit-mixteure.
- Materials-fluid-change-create-name-polyborosilne-density(1219 kg/m3)-Viscocity(.789 m/s)-change –fluid-change-fluent data base (silicon carbide)-copy.
- Phase-polyborosiloxane (primary phase) – drag coefficent –schiiller namuann . Secondary phase-silicon carbide-grangular-properties-diameter(22µm)
- Phase-primary phases-select polyborosiloxane.

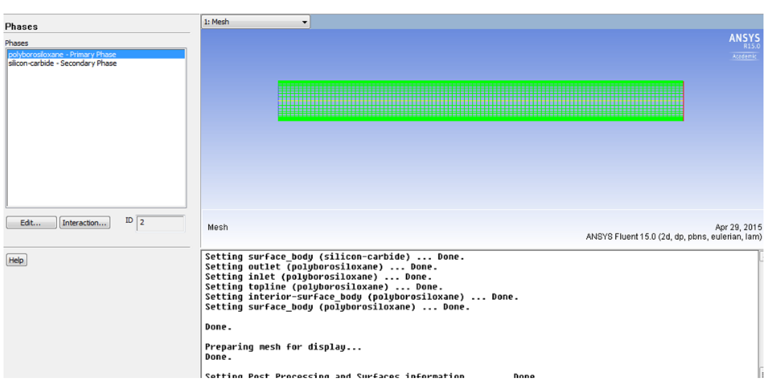

Fig.13 primary phases polyborosiloxane.

- Phases-secondary phases-silicon carbide.

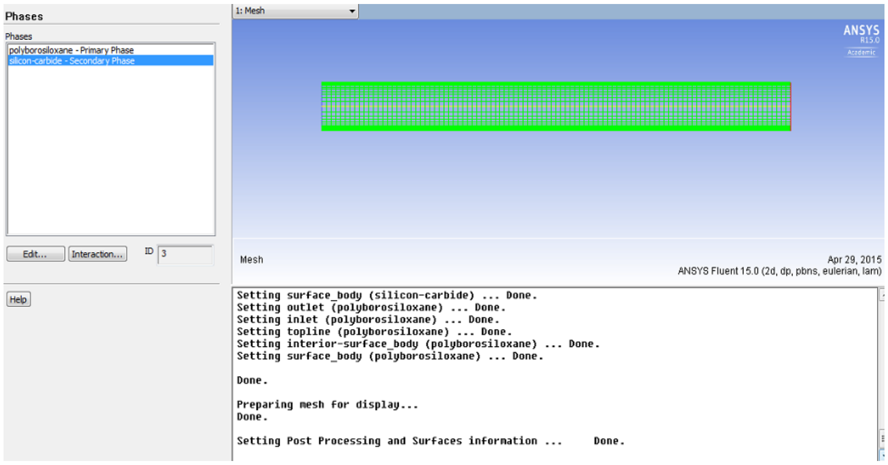

Fig.14 second phases-silicon carbide.

- Cell zone condition-phase-polyborosloxane-type-fluid-phase-silicon carbide– type solid.
- Solution control-under relaxation factors –pressure (0.45)- momentum (0.7)-volume fraction(0.50) monitors-residual print plot-edit-convergence criterion- absolute.
- Solution intilzation method-standard- compute from all zone-refrence frame absolute-intial values-silicon carbide volume fraction(.50)
- Run calculation-time step sizes (0.001) –number of time stpes (1000) –max iteration/time step(40) – reporting interval (1)

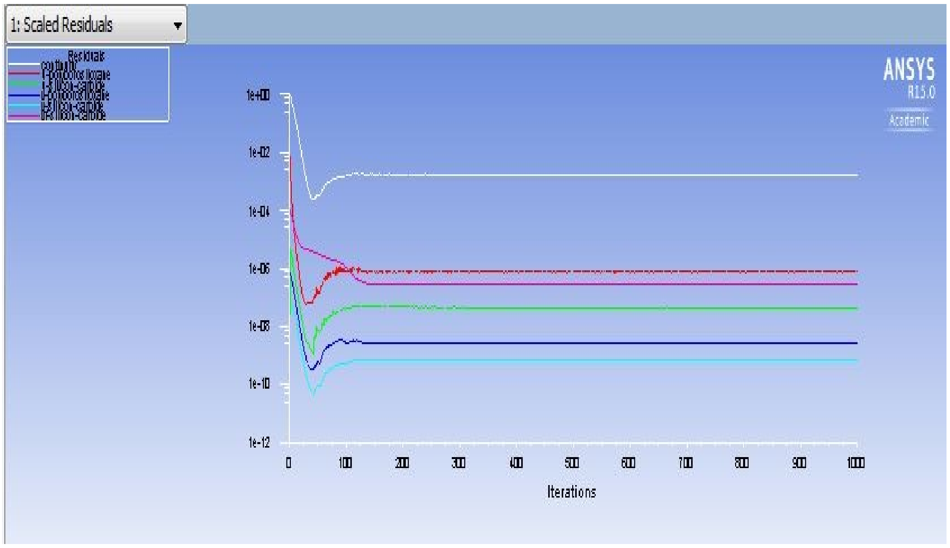

Fig.15 Run calculation.

Iterations are stopped when the residuals for the two-component velocity and the continuity equation approached an asymptotic value. After the iteration is stopped the velocity and pressure distribution, the axial stress and the radial stresses are found as follows.

3.4 Force acting during AFM process.

The figure.16 shows abrasive particle acting on the work piece and force induced during AFM process.

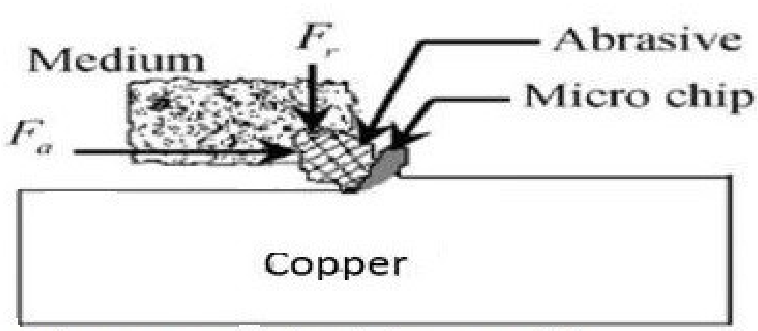

Fig16 Forces acting during AFM[3]

3.4.1 Mechanism of material removal.

Jain et.al said that, when extrusion pressure is applied on the medium like polyborosiloxane + grease and silicon carbide by the cylinder of piston there are two forces generated .i.e normal or radial force and axial force. Normal force works for indentation of the abrasive grain on the work piece surface. The next force is axial force which works for the removal of material from the work piece surface.

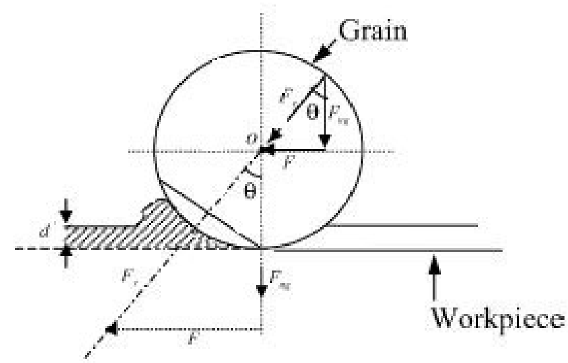

Fig.17 Depth of indentation due radia force [2]

Fig.17 depicts abrasive grain indentation on the work piece which cause's material removal from work piece by the forces are generated like radial force and axial force.

- Radial force is responsible for the indentation of the abrasive grain on the work piece surface.

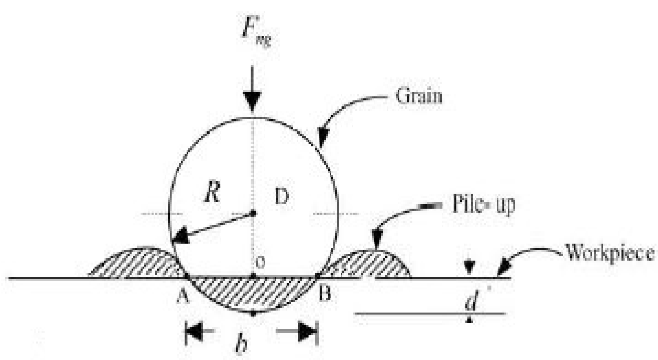

Fig.18 indentation of grain into the work piece with side pile-up [1]

- And axial force is responsible for the material removal from the work piece surface.

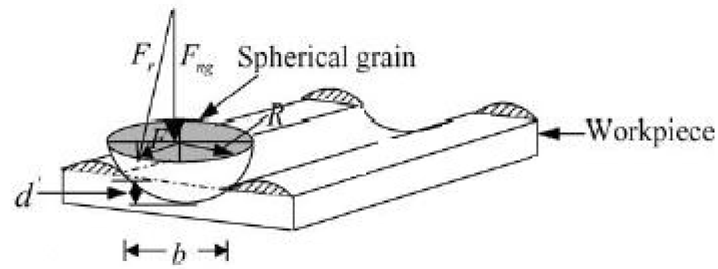

Fig.19hemisphere normal to the direction of motion [1]

During AFM process Fn normal force is acting on the abrasive grain causing indentation into the work piece with depth being "t".

The normal force can be caluculated.

$$F_n = \sigma_{rad} \times A \quad \text{-------------------}(1)$$

$$\text{Where} \quad A = \pi \times \left(\frac{d_g}{2}\right)^2 \quad \text{----------------------}(2)$$

In the above equation of area, d_g is abrasive grain diameter and radial stress σ_{rad} is acting on the surface of work piece.

The indentation diameter d_i can be calculated as.

$$d_i = \sqrt{d_g^2 - \left(dg - \frac{f_n \times 2 \times 10^{-6}}{9.81 \times H_{BHN} \times \pi \times d_g}\right)^2} \quad \text{-------------------------}(3)$$

H_{bhn} = brinell hardness number of the works piece material

H_{bhn} = 35BHN

Indentation depth can be calculated as.

$$t = \frac{d_g}{2} - \frac{1}{2}\sqrt{d_g^2 - d_i^2} \qquad \text{----------------------------(4)}$$

During machining process shear acts on the work piece surface and the axial shear force is greater than the reaction force on abrasive grits at the projected area.

Projected area can calculated as.

$$A' = \frac{d_g^2}{2}\ \sin^{-1}\frac{2\sqrt{t\,(d_g - t)}}{d_g} - \sqrt{t(dg - t)\left(\frac{d_g}{2} - t\right)} \qquad \text{-----------------(5)}$$

The axial force can be calculated as.

$$F_a = (A - A') \times \tau_y \qquad \text{------------------------(6)}$$

Reacction force can be calculated as.

$$F_r = A' \times \sigma_y \qquad \text{-----------------(7)}$$

Volume of material can calculated as.

$$V_a = A' \times l_i \qquad \text{------------(8)}$$

And where l_i is grain contact length on the work piece.

$$l_i = r \times \theta \qquad \text{------------------ (9)}$$

Where θ is abrasive grain contact angle on the work piece.

θ can be caluculated as.

$$\cos\theta = \frac{d_i}{r} \qquad \text{------------------(10)}$$

CHAPTER 4

4.1 Results and discussion of media flow inside a pipe.

The above simulation procedure was given 1000 iteration and one interval. After complition of Iteration, the pressure distribution and velocity distribution were found . Also radial stress and axial stress were taken. .

4.1.1 ***Velocity distribution*** .

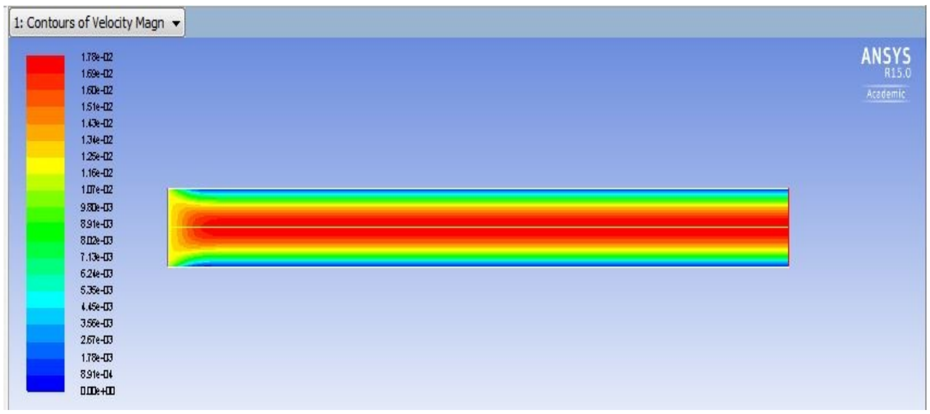

Fig.20 velocity distribution.

- We assumed laminar flow in modelling process .

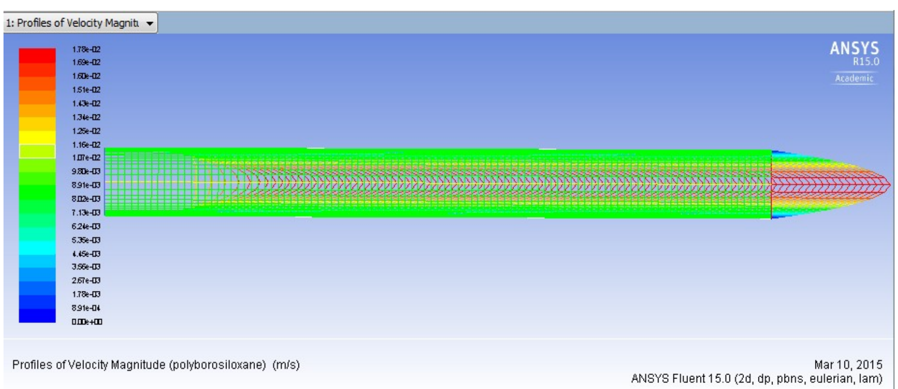

Fig.21 Velocity profile in side the pipe.

Fig.20 shows that media flow of velocity is maximum at centreline and minimum velocity at wall.

4.1.2 ***Plot of velocity with position*** .

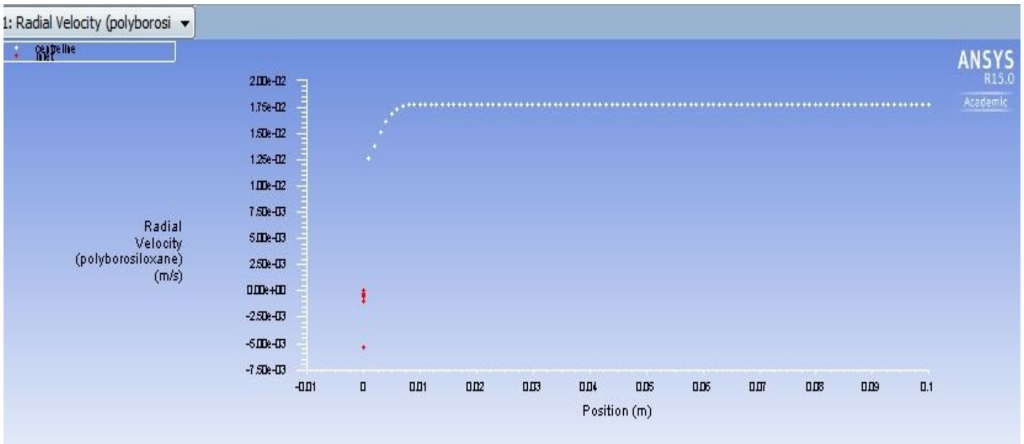

Fig.22 Velocity with postion.

From fig.22 we can see the magnitude of velocity increase from zero to finite value at the center line.

4.1.3 ***Pressure distribution*** .

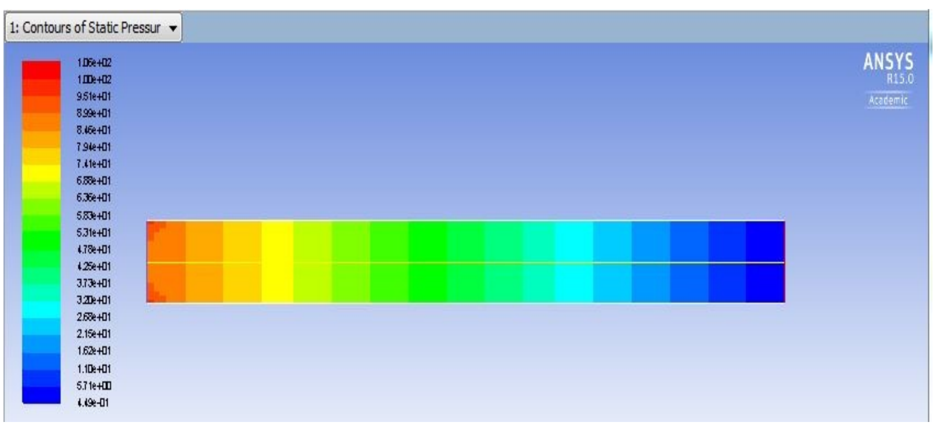

Fig.23 pressure distribution.

From the figure.23 of pressure distribution it is found that the pressure decreases gradually from inlet to outlet.

When the mixed flow i.e silicon carbide and polyborosine was introduced into the cylindrical pipe, pressure decreases due to extrusion pressure by the cylindrical   piston.

4.1.4 ***Plot of static pressure distribution*** **.**

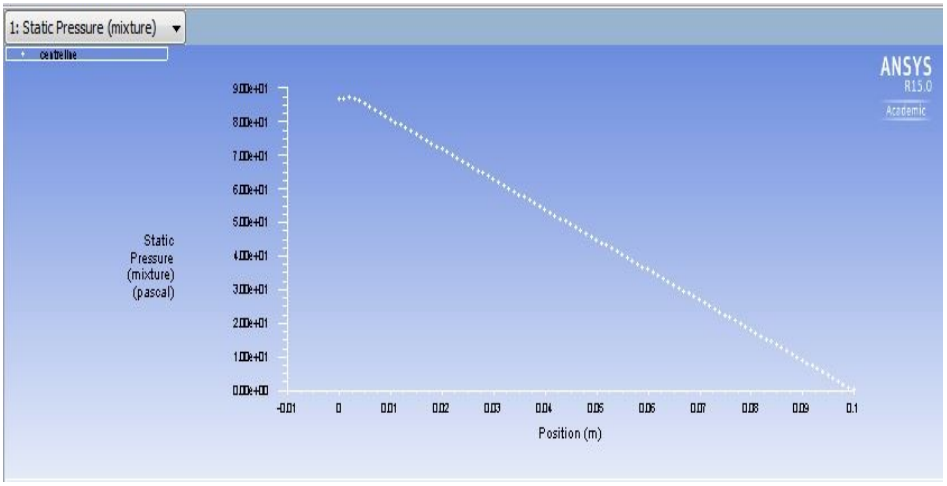

Fig.24 Plot pressure with pressure.

From the figure.24 we can see the pressure dropping from a finite value to zero at the exit.

4.1.5 ***Plot of axial wall shear stress*** **.**

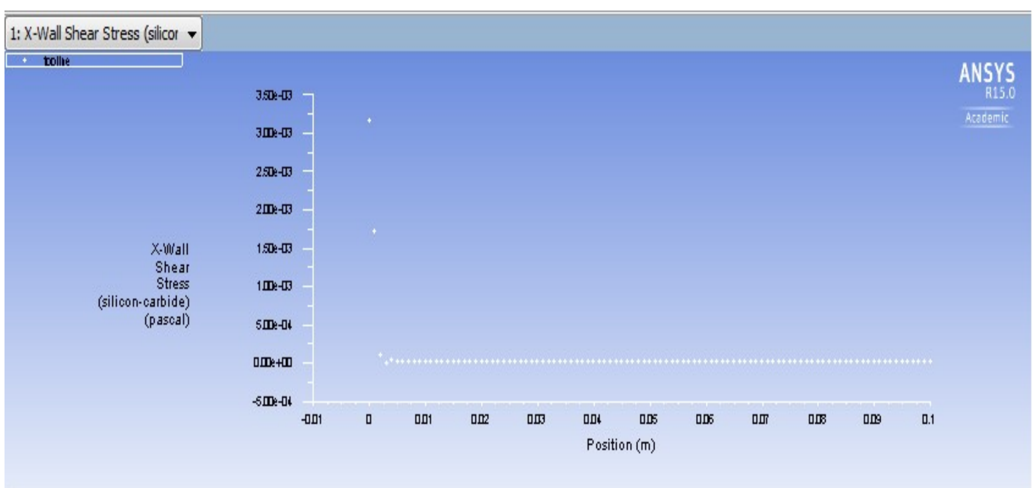

Fig.25 Axial wall shear stress.

4.1.6 ***Plot of radial wall shear stress*** .

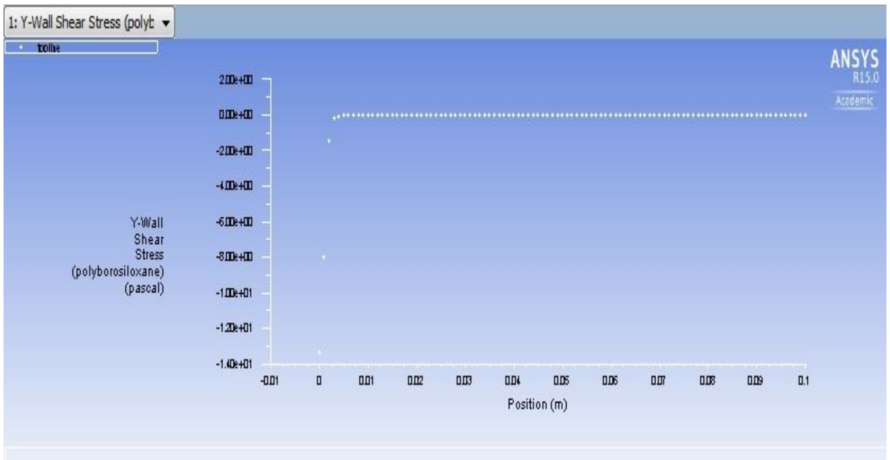

Fig.26 Radial wall shear stress .

The radial stress on the work piece found from the CFD is.

$\sigma_{rad} = 2.194185 \times 10^{-8}$ Pa

The radial stress value is used to find normal force employing equatio no .(1)

$F_n = 8.34079 \times 10^{-8}$N

The value of normal force (F_n) was put in equation no (3) to get indentation diameter.

$d_i = 4.68 \times 10^{-6}$m

The value of indentation diameter (d_i) was put in equation no.(4) to calculate depth of indentation .

$t = 1.09 \times 10^{-5}$m

Then depth of indentation value was substituted in equation no .(5) and projected area was calculated.

The projected area value is .

$A' = 6.9031 \times 10^{-14}\ m^2$

The value of projected area substituted in equation no (7) gives reaction force .

$F_r = 1.51466 \times 10^{-21}$N

From CFD calculation, axial stress on the work piece material was found to be.

$\tau = 2.147359 \times 10^{-6}$ Pa

Putting it in equation no (6), we got the axial force.

$F_a = 8.161337 \times 10^{-16}$N

In which calculated some values i.e is indentation diameter ,depth of indentation,reaction force and axial force by the abrasive flow machining so jain et.al sayed the axial force greater than the reaction force.in which modelling process found two forces i.e is axial force and reaction force .we have found that axial force is very much higher 10^5 than the reaction force.

- <u>**NOTE**</u> **Fa >Fr**

Also from the equation no.(10).and we can get value of contact length.

$L_i = 1.70 \times 10^{-3}$ m

Now the putting of value of contact length inequation no.(8). And we can get value of volume of material removal.

$V_a = 11.73257 \times\times 10^{-16}\ m^3$

4.2 Results and discussion of media flow inside arbitrary shape.

Velocity distribution **.**

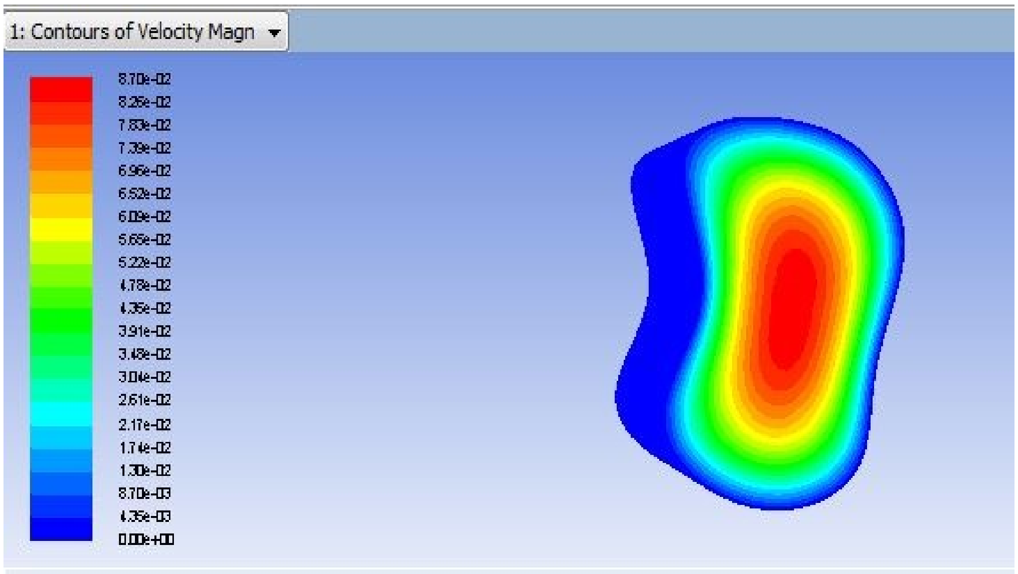

Fig.27 velocity distribution with arbitrary shape.

From the figure.27 maximum velocity at center and gradually decreases to boundaries of work piece.

4.2.1 ***Plot of velocity magnitude with postion*** .

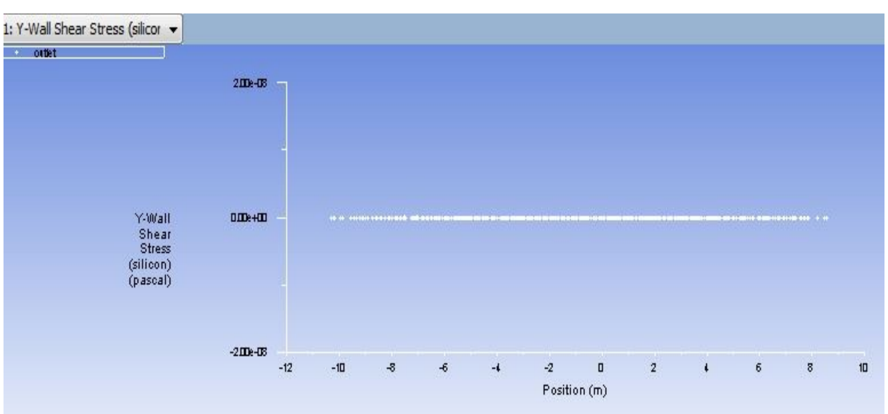

Fig.28 velocity with postion.

4.2.2 ***Pressure distribution*** .

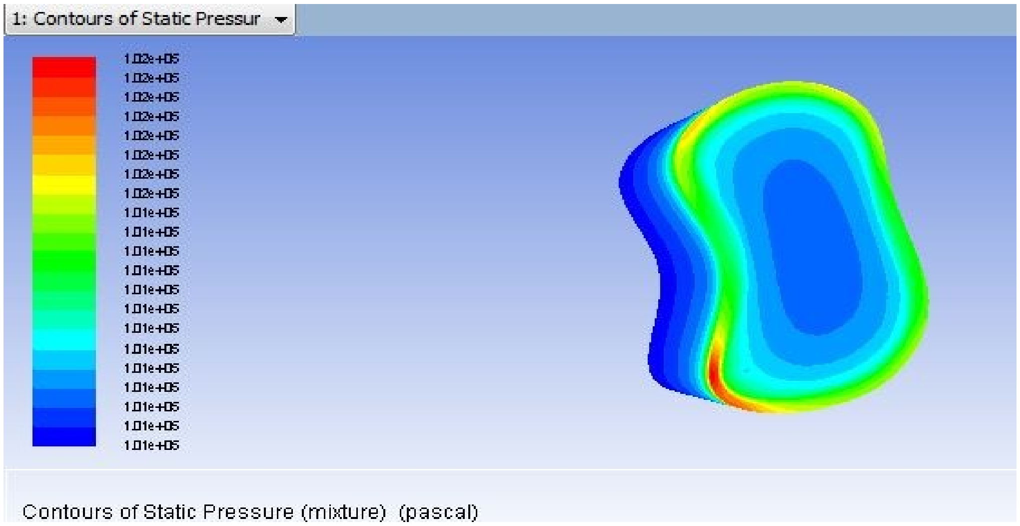

Fig.29 Pressure distribution with arbitrary shape.

From the figure.29 pressure distribution is constant throught out inlet complex body.

4.2.3 ***Plot of axial wall shear stress***.

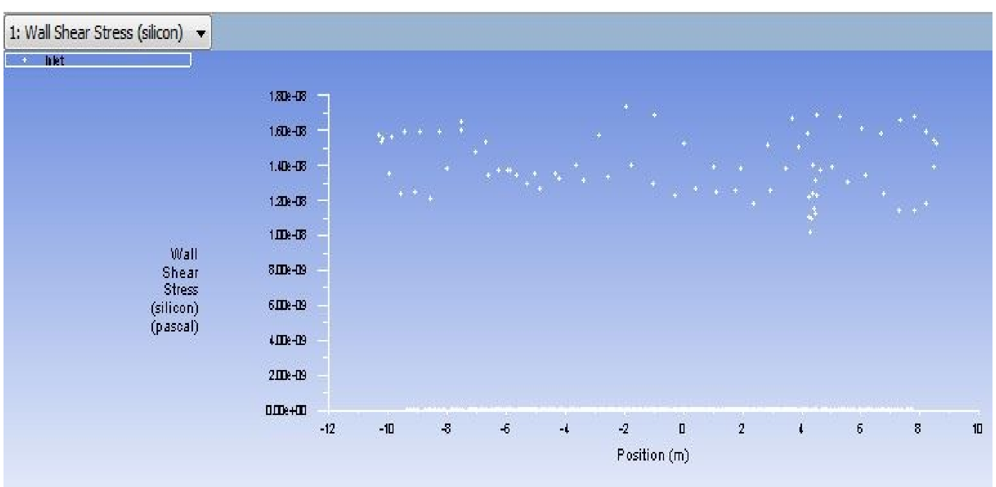

Fig30 axial wall shear stress.

4.2.4 ***Plot of radial wall shear stress***.

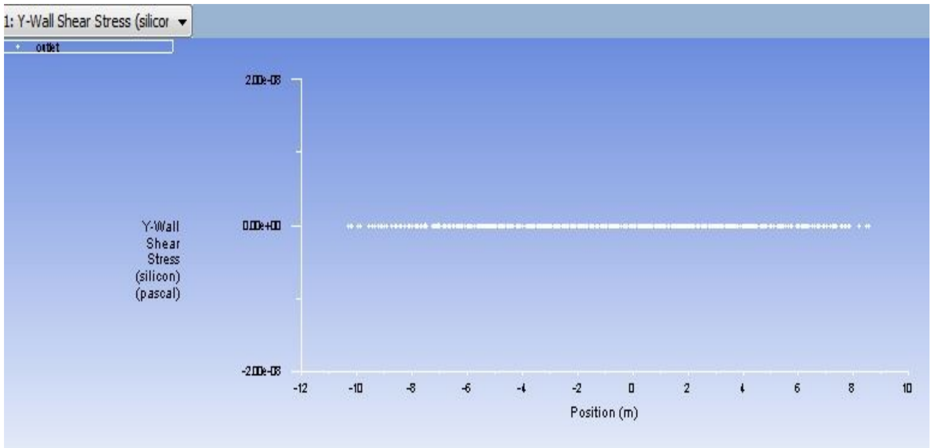

Fig.31 Radial wall shear stress.

The radial stress on the work piece found from the CFD is.

$\sigma_{rad} = 3.82085\times10^{-12}$ Pa

The radial stress value is used to find normal force employing equatio no .(1)

$F_n = 1.4524\times10^{-9}$ N

The value of normal force (F_n) was put in equation no (3) to get indentation diameter.

$d_i = 1.22\times10^{-8}$ m

The value of indentation diameter (d_i) was put in equation no.(4) to calculate depth of indentation .

$t = 5\times10^{-8}$ m

Then depth of indentation value was substituted in equation no .(5) and projected area was calculated.

$A' = 3.4189 \times 10^{-9}\ m^2$

The value of projected area substituted in equation no (7) gives reaction force .

$F_r = 1.3060 \times 10^{-20}$ N

From CFD calculation axial stress on the work piece material is.

$t = 7.4265 \times 10^{-6}$ Pa

Putting it in equation no (6), we got the axial force.

$F_a = 2.256 \times 10^{-15}$ N

In which calculated some values i.e is indentation diameter ,depth of indentation,reaction force and axial force by the abrasive flow machining so jain et.al sayed the axial force greater than the reaction force.in which modelling process found two forces i.e is axial force and reaction force .we have found that axial force is very much higher 10^5 than the reaction force.

- <u>**NOTE**</u> **Fa >Fr**

Also from the equation no.(10).and we can get value of contact length.

$L_i = 1.970 \times 10^{-3}$ m

Now the putting of value of contact length inequation no.(8). And we can get value of volume of material removal.

$V_a = 6.7625 \times 10^{-12}\ m^3$

CHPATER 5

Optimization

Optimization is an effective tool use by researchers to solve problems based on reality, through this technique real function can be minimized or maximized depending on the requirement of the problem. It consist of algorithm defined to generate the best available out come from systematically choosing the input parameters.

5.1 Optimization techniques.

Mathematical programming can be used to denote one problem that normalizes all deterministic operations research methodologies [25].The problem formulation is as follows:

Symbolized as:

Optimize $f\,(x_1,x_2,x_3,x_4,x_5..........x_n)$

Subject to ($S_{lj} \leq x_j \leq S_{uj}$)

$L_i \leq g_i\,(x_1,x_2, x_3, x_4,......x_n) \leq U_i.$

Where j is 1, 2, 3 ... n, i is 1, 2, 3.... m.

In present study $f\,(x_1,x_2,x_3,x_4,x_5..........x_n)$ its found that connected objective function with $x_1,x_2,x_3,x_4,x_5..........x_n$ its controlled variable. x_j value should fall relation with mentioned very low limit S_{lj}, and the upper limit S_{uj}.the objective function $g_i\,(x_1,x_2, x_3, x_4,......x_n)$ are less than $f\,(x_1,x_2,x_3,x_4,x_5..........x_n)$**.** Its these objective function are constrained as constraints for the multiple objective optimizes .for example $L_i \leq g_i$ $(x_1,x_2,\ x_3,\ x_4,\ldots\ldots x_n\ )_{\leq\ Ui.}$ This type of constraints. The constraints would fall indoors the domain of L_i& U_i .

5.1.2 Test for significance on individual model coefficients.

This is one of the elimination process test structure for prototypical optimization by adding or deleting coefficients from side to side back ward rejection. Forward calculation or stepwise exclusion/addition/interchange can be done. It engages the resolve of the p-value or probability value, usually involving the risk of a certain hypothesis. For model a probability value >F value on an F-test informs the proportion of time you would anticipate to get the stated F-value if no factor things are significant. The "Prob. Value > F" indomitable can be matched with the preferred probability or α-level. In common, the lowest order polynomial would be selected to adequately designate the system.

5.1.3 Test for significance of the regression model.

This test is completed as an ANOVA analysis by computing the F-ratio, which is the ratio amongst the regression mean square and the mean square error. The F-ratio, similarly called The variance ratio is the ratio of difference outstanding to the conclusion of a variable and difference due to the mistake stint. This ratio is secondhand to calculate the importance of the exemplary under investigation With detail to the modification of all the terms fused in the error term at the chosen Importance α-level. A major model is preferred.

5.1.4 Test for lack-of-fit.

As imitate measurements are available, a trial indicating the consequence of the replicate error in evaluation to the typical reliant error can be performed. These trial boundaries the residual or error sum of squares into two portions, one that is payable to clean error, which is based on the repeat measurements, and the other due to lack-of-fit based on the model results. The test digit for lack-of-fit is the ratio in among the lack-of-fit mean square and the clean error mean square. As formerly, this F-test statistic can be used to find out as to whether the lack-of-fit error is substantial or otherwise at the chosen importance α-level. Insignificant lack-of-fit is preferred as significant lack-of-fit designates that there potency be donations in the regression of response bond that are not reported for by the model.

5.2 Results and discussions.

In this present study, the characteristics parameters of (AFM) abrasive flow machining are taken with three values of variables. For optimization of this operation "Taguchi l9 orthogonal array" was used. Then the out response i.e .depth of indentation are recorded in given table below. For the optimazitation Minitab Version 16 was used.

Table. 1: Value of Input Process Parameters.

Sl no	**Extrusion pressure (Pa)**	**Velocity (m/s)**
1	35	0.0253
2	40	0.035
3	45	0.045

5.2.1. <u>Design of circular pipe.</u>

Using Taguchi's technique, optimization of the output response, depth of indentation from the input parameters like extrusion pressure, mesh size and inlet velocity.

Table.2. L9 orthogonal array and value response for depth of indentation.

Sl. No	Extrusion Pressure	Velocity	Mesh size	Depth of Indentation
1	35	.0253	400	$10.06683*10^{-6}$
2	35	.035	500	$9.3051*10^{-6}$
3	35	.045	600	$7.4344*10^{-6}$
4	40	.0253	500	$9.30508*10^{-6}$
5	40	.035	600	$7.7172*10^{-6}$
6	40	.045	400	$10.599*10^{-6}$
7	45	.0253	600	$7.71788*10^{-6}$
8	45	.035	400	$5.188*10^{-7}$
9	45	.045	500	$9.19181*10^{-6}$

5.2.2. Depth of Indentation.

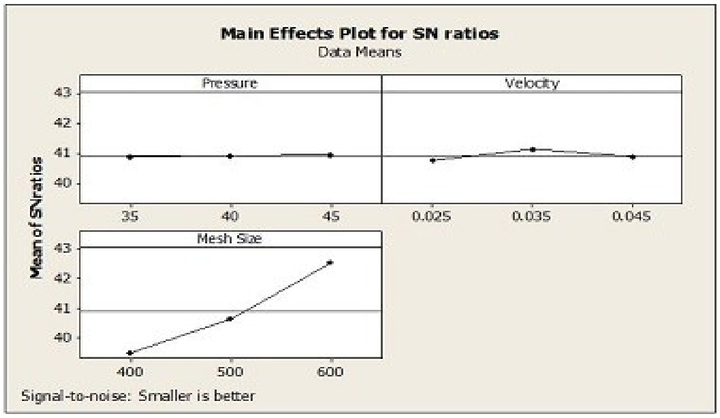

Fig.32 Main effects plot for SN ratios

From the main effects plot for SN ratio obtained using Taguchi technique, it can be observed that the depth of indentation is minimum at value of high pressure 45Pa, the value of high velocity 0.045m/s and value of high mesh size 600mm.

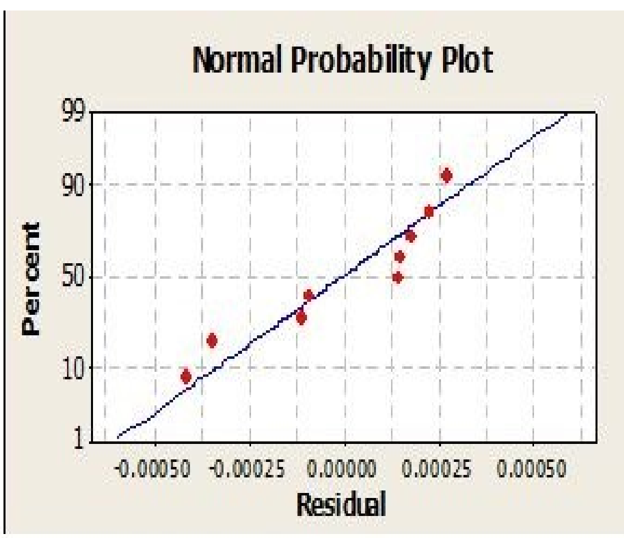

Fig.33 Probability

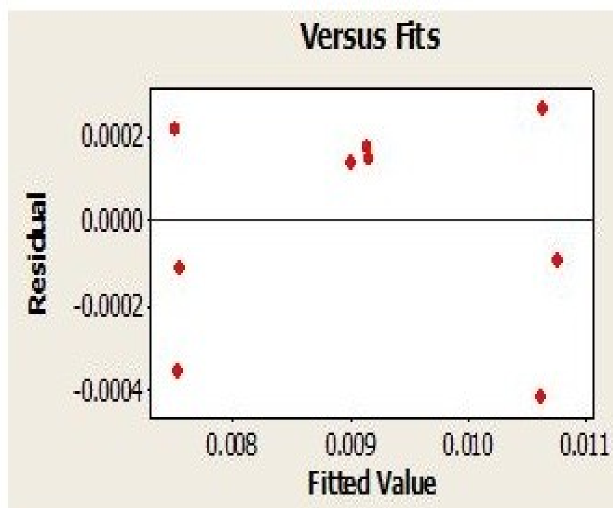

Fig.34 Versus Fits

From the figure.33 is normal probability plot of our response of depth of indentation that is plotted. we observed that is all small points almost nearly to the reference line it means that for depth of indentation are correct. Then the fitted value vs. Residual value plot is give figure .34 in which plot some points is formed.so the input parameter are fitted well in 90% confidence interval.

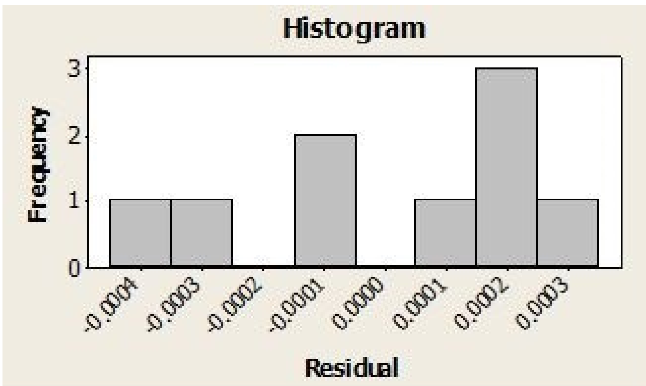

Fig.35 Histogram

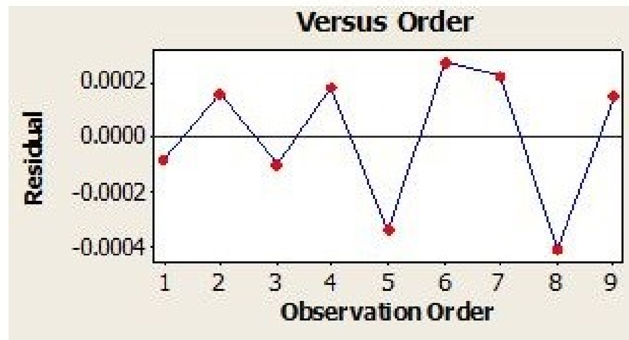

Fig.36 Versus order

From the histogram plot of depth of indentation in which all columns are formed into normal probability distribution. Its a successful manner of the realistic analysis of abrasive flow machining. The plot between observation and residual values from the figure.36 we observed from that figure minimum depth of indentation is 8^{th} and maximum depth of indentation is 6^{th} of the values obtained.

5.2.3. Design of arbitrary shape.

Using Taguchi's technique, optimization of the output response, depth of indentation from the input parameters like extrusion pressure, mesh size and inlet velocity.

Table.3. L9 orthogonal array and value response for depth of indentation.

Sl. No	Ex. Pressure	Velocity	Mesh size	Depth of Indentation
1	35	.0253	400	$10.66*10^{-6}$
2	35	.035	500	$9.4025*10^{-6}$
3	35	.045	600	$10.868*10^{-6}$
4	40	.0253	500	$9.191*10^{-6}$
5	40	.035	600	$7.717*10^{-6}$
6	40	.045	400	$10.765*10^{-6}$
7	45	.0253	600	$7.717*10^{-6}$
8	45	.035	400	$10.666*10^{-6}$
9	45	.045	500	$9.191*10^{-6}$

5.2.4. Depth of Indentation.

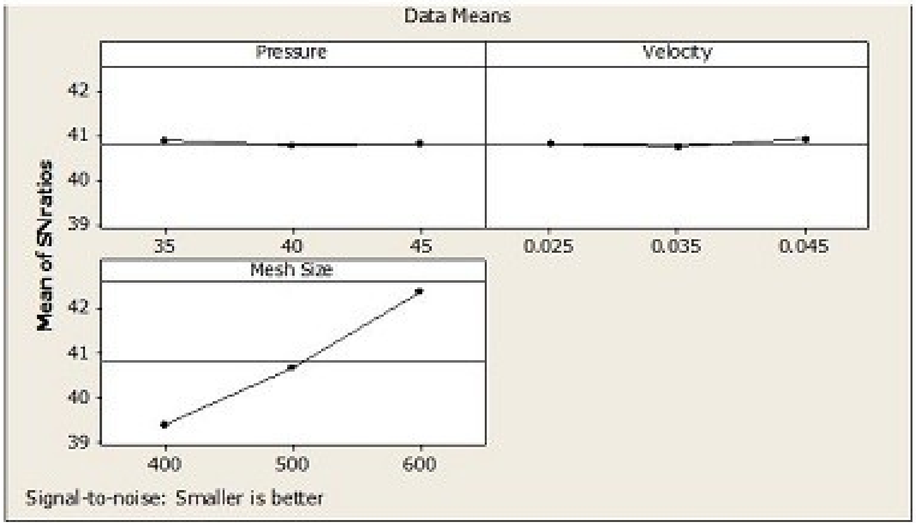

Fig.37 Main effects plot for Arbitrary shape.

From the main effects plot for SN ratio obtained using Taguchi technique, it can be observed that the depth of indentation is minimum at value of high pressure 45, the value of high velocity 0.045 and value of high mesh size 600.

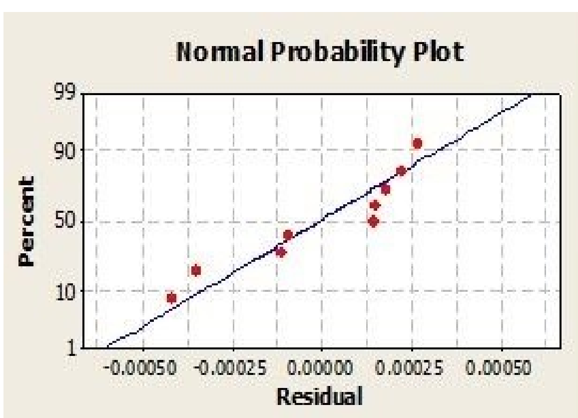

Fig.38 normal probability.

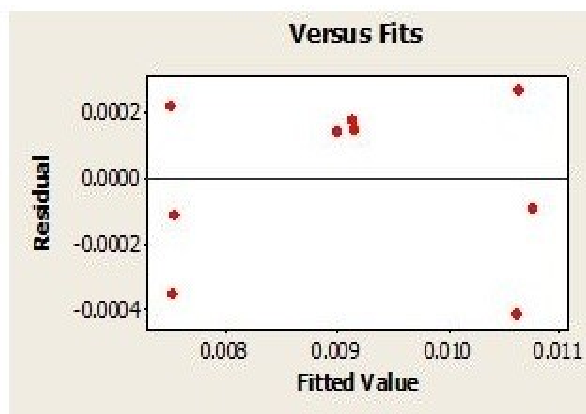

Fig.39 versus fits.

From the figure.38 is normal probability plot of our response of depth of indentation that is plotted. we observed that is all small points almost nearly to the reference line it means that for depth of indentation are correct. Then the fitted value vs. Residual value plot is give figure .39 in which plot some points is formed.so the input parameter are fitted well in 90% confidence interval.

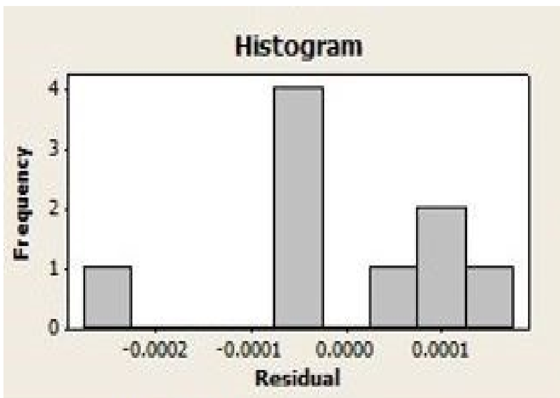

Fig.40 histogram.

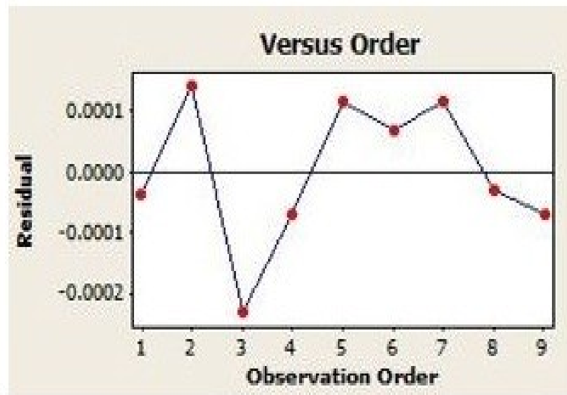

Fig.41 versus order.

From the histogram plot of depth of indentation in which all columns are formed into normal probability distribution. Its a successful manner of the realistic analysis of abrasive flow machining. The plot between observation and residual values from the figure.41 we observed from that figure minimum depth of indentation is 3rd and maximum depth of indentation is 2nd of the values obtained.

CHAPTER 6

CONCLUSION

For the present research work, the following conclusion has been drawn.

The present study CFD simulation of AFM in a circular pipe and arbitrary shape taking different parameters. In which computational fluid dynamics is used to simulate the forces. The present work develops CFD simulation of AFM on a work piece with two different profile and comparison are drawn based on the output responses, and that simulation forces compare with existing experimental forces.

1.The optimal condition of input variables are at 600 of mesh size, 45 bar of pressure and 0.035 m/s of velocity for the circular profile of the pipe which give best result for depth of indentation.

2. The optimal condition of input variables are at 600 of mesh size, 35 bar of pressure and 0.045 m/s of velocity for the arbitrary profile of the pipe which give best result for depth of indentation.

3. From CFD analysis, the axial stresses, radial stress at the work piece surface are generated and from these values, the axial force and normal forces are calculated.

4. The ANOVA revealed that the mesh size is the most significant factor influencing the response variables examined.

5. The reduced linear models developed using regression analysis was reasonably perfect and can be used for prediction within the limits of the factors investigated.

CHAPTER 7

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